versus speed and use it with the applicable normalized duty cycle in the standard-setting part to generate a reference duty cycle as described in §1065.610. Calculate the total reference work, W_{ref}, as described in §1065.650.

(ii) Multiply your CVS total molar flow rate by the time interval of the duty cycle, $\Delta t_{dutycycle}$. The result is the total diluted exhaust flow of the n_{dexh}.

(iii) Use your estimated values as described in the following example calculation:

$$\bar{x}_{NMHC} = \frac{e_{std} \cdot W_{ref}}{M \cdot \dot{n}_{dexh} \cdot \Delta t_{duty\ cycle}} \qquad \text{Eq. 1065.602-15}$$

Example:

e_{NMHC} = 1.5 g/(kW·hr)
W_{ref} = 5.389 kW·hr
M_{NMHC} = 13.875389 g/mol = 13.875389 · 10^{-6} g/µmol
$\dot{n}_{dexh}$ = 6.021 mol/s
$\Delta t_{dutycycle}$ = 30 min = 1800 s

$$\bar{x}_{NMHC} = \frac{1.5 \cdot 5.389}{13.875389 \cdot 10^{-6} \cdot 6.021 \cdot 1800}$$

$\bar{x}_{NMHC}$ = 53.8 µmol/mol

[70 FR 40516, July 13, 2005, as amended at 73 FR 37324, June 30, 2008; 75 FR 23044, Apr. 30, 2010; 76 FR 57452, Sept. 15, 2011]

§ 1065.610 Duty cycle generation.

This section describes how to generate duty cycles that are specific to your engine, based on the normalized duty cycles in the standard-setting part. During an emission test, use a duty cycle that is specific to your engine to command engine speed, torque, and power, as applicable, using an engine dynamometer and an engine operator demand. Paragraph (a) of this section describes how to "normalize" your engine's map to determine the maximum test speed and torque for your engine. The rest of this section describes how to use these values to "denormalize" the duty cycles in the standard-setting parts, which are all published on a normalized basis. Thus, the term "normalized" in paragraph (a) of this section refers to different values than it does in the rest of the section.

(a) *Maximum test speed, f_{ntest}.* This section generally applies to duty cycles for variable-speed engines. For constant-speed engines subject to duty cycles that specify normalized speed commands, use the no-load governed speed as the measured f_{ntest}. This is the highest engine speed where an engine outputs zero torque. For variable-speed engines, determine the measured f_{ntest} from the power-versus-speed map, generated according to §1065.510, as follows:

(1) Based on the map, determine maximum power, P_{max}, and the speed at which maximum power occurred, f_{nPmax}. If maximum power occurs at multiple speeds, take f_{nPmax} as the lowest of these speeds. Divide every recorded power by P_{max} and divide every recorded speed by f_{nPmax}. The result is a normalized power-versus-speed map. Your measured f_{ntest} is the speed at which the sum of the squares of normalized speed and power is maximum. Note that if multiple maximum values are found, f_{ntest} should be taken as the lowest speed of all points with the same maximum sum of squares. Determine f_{ntest} as follows:

$$f_{ntest} = f_{ni} \text{ at the maximum of } \left(f_{nnormi}{}^{2} + P_{normi}{}^{2}\right)$$

Eq. 1065.610-1

Where:

f_{ntest} = maximum test speed.

i = an indexing variable that represents one recorded value of an engine map.

f_{nnormi} = an engine speed normalized by dividing it by f_{nPmax}.

P_{normi} = an engine power normalized by dividing it by P_{max}.

Example:

$(f_{nnorm1} = 1.002,\ P_{norm1} = 0.978,\ f_{n1} = 2359.71)$

$(f_{nnorm2} = 1.004,\ P_{norm2} = 0.977,\ f_{n2} = 2364.42)$

$(f_{nnorm3} = 1.006,\ P_{norm3} = 0.974,\ f_{n3} = 2369.13)$

$(f_{nnorm1}^2 + P_{norm1}^2) = (1.002^2 + 0.978^2) = 1.960$

$(f_{nnorm2}^2 + P_{norm2}^2) = (1.004^2 + 0.977^2) = 1.963$

$(f_{nnorm3}^2 + P_{norm3}^2) = (1.006^2 + 0.974^2) = 1.961$

maximum = 1.963 at i = 2

f_{ntest} = 2,364.42 r/min

(2) For engines with a high-speed governor that will be subject to a reference duty cycle that specifies normalized speeds greater than 100%, calculate an alternate maximum test speed, $f_{ntest,alt}$, as specified in this paragraph (a)(2). If $f_{ntest,alt}$ is less than the measured maximum test speed, f_{ntest}, determined in paragraph (a)(1) of this section, replace f_{ntest} with $f_{ntest,alt}$. In this case, $f_{ntest,alt}$ becomes the ''maximum test speed'' for that engine. Note that §1065.510 allows you to apply an optional declared maximum test speed to the final measured maximum test speed determined as an outcome of the comparison between f_{ntest}, and $f_{ntest,alt}$ in this paragraph (a)(2). Determine $f_{ntest,alt}$ as follows:

$$f_{ntest,alt} = (f_{nhi,idle} - f_{nidle})/\%\,speed_{max} + f_{nidle}$$

Eq. 1065.610-2

Where:

$f_{ntest,alt}$ = alternate maximum test speed

$f_{nhi,idle}$ = warm high-idle speed

f_{nidle} = warm idle speed

$\%\ speed_{max}$ = maximum normalized speed from duty cycle

Example:

$f_{nhi,idle}$ = 2,200 r/min

f_{nidle} = 800 r/min

$\%\ speed_{max}$ = 105% (Nonroad CI Transient Cycle)

$f_{ntest,alt}$ = (2,200 − 800)/105% + 800

$f_{ntest,alt}$ = 2,133 r/min

(3) For variable-speed engines, transform normalized speeds to reference speeds according to paragraph (c) of this section by using the measured maximum test speed determined according to paragraphs (a)(1) and (2) of this section—or use your declared maximum test speed, as allowed in §1065.510.

(4) For constant-speed engines, transform normalized speeds to reference speeds according to paragraph (c) of this section by using the measured no-load governed speed—or use your declared maximum test speed, as allowed in §1065.510.

(b) *Maximum test torque, T_{test}.* For constant-speed engines, determine the measured T_{test} from the power-versus-speed map, generated according to §1065.510, as follows:

(1) Based on the map, determine maximum power, P_{max}, and the speed at which maximum power occurs, f_{nPmax}. If maximum power occurs at multiple speeds, take f_{nPmax} as the lowest of these speeds. Divide every recorded power by P_{max} and divide every recorded speed by f_{nPmax}. The result is a normalized power-versus-speed map. Your measured T_{test} is the torque at which the sum of the squares of normalized speed and power is maximum. Note that that if multiple maximum values are found, T_{test} should be taken as the highest torque of all points with the same maximum sum of squares. Determine T_{test} as follows:

$$T_{\text{test}} = T_{\text{i}} \text{ at the maximum of } \left(f_{\text{nnormi}}{}^{2} + P_{\text{normi}}{}^{2}\right)$$

Eq. 1065.610-3

Where:

T_{test} = maximum test torque.

Example:

(f_{nnorm1} = 1.002, P_{norm1} = 0.978, T_1 = 722.62 N·m)
(f_{nnorm2} = 1.004, P_{norm2} = 0.977, T_2 = 720.44 N·m)
(f_{nnorm3} = 1.006, P_{norm3} = 0.974, T_3 = 716.80 N·m)
($f_{\text{nnorm1}}{}^2 + P_{\text{norm1}}{}^2$) = ($1.002^2 + 0.978^2$) = 1.960
($f_{\text{nnorm1}}{}^2 + P_{\text{norm1}}{}^2$) = ($1.004^2 + 0.977^2$) = 1.963
($f_{\text{nnorm1}}{}^2 + P_{\text{norm1}}{}^2$) = ($1.006^2 + 0.974^2$) = 1.961
maximum = 1.963 at__i = 2
$T_{\text{test\_\_}}$ = 720.44 N·m

(2) Transform normalized torques to reference torques according to paragraph (d) of this section by using the measured maximum test torque determined according to paragraph (b)(1) of this section—or use your declared maximum test torque, as allowed in §1065.510.

(c) *Generating reference speed values from normalized duty cycle speeds.* Transform normalized speed values to reference values as follows:

(1) *% speed.* If your normalized duty cycle specifies % speed values, use your warm idle speed and your maximum test speed to transform the duty cycle, as follows:

$$f_{\text{nref}} = \%\, speed \cdot (f_{\text{ntest}} - f_{\text{nidle}}) + f_{\text{nidle}}$$

Eq. 1065.610-4

Example:

% speed = 85%
f_{ntest} = 2,364 r/min
f_{nidle} = 650 r/min
f_{nref} = 85% · (2,364 − 650) + 650
f_{nref} = 2,107 r/min

(2) *A, B, and C speeds.* If your normalized duty cycle specifies speeds as A, B, or C values, use your power-versus-speed curve to determine the lowest speed below maximum power at which 50% of maximum power occurs. Denote this value as n_{lo}. Take n_{lo} to be warm idle speed if all power points at speeds below the maximum power speed are higher than 50% of maximum power. Also determine the highest speed above maximum power at which 70% of maximum power occurs. Denote this value as n_{hi}. If all power points at speeds above the maximum power speed are higher than 70% of maximum power, take n_{hi} to be the declared maximum safe engine speed or the declared maximum representative engine speed, whichever is lower. Use n_{hi} and n_{lo} to calculate reference values for A, B, or C speeds as follows:

$$f_{\text{nrefA}} = 0.25 \cdot (n_{\text{hi}} - n_{\text{lo}}) + n_{\text{lo}}$$

Eq. 1065.610-5

$$f_{\text{nrefB}} = 0.50 \cdot (n_{\text{hi}} - n_{\text{lo}}) + n_{\text{lo}}$$

Eq. 1065.610-6

$$f_{\text{nrefC}} = 0.75 \cdot (n_{\text{hi}} - n_{\text{lo}}) + n_{\text{lo}}$$

Eq. 1065.610-7

Example:

n_{lo} = 1005 r/min
n_{hi} = 2385 r/min
f_{nrefA} = 0.25 · (2385 − 1005) + 1005
f_{nrefB} = 0.50 · (2385 − 1005) + 1005
f_{nrefC} = 0.75 · (2385 − 1005) + 1005
f_{nrefA} = 1350 r/min
f_{nrefB} = 1695 r/min
f_{nrefC} = 2040 r/min

(3) *Intermediate speed.* If your normalized duty cycle specifies a speed as ''intermediate speed,'' use your torque-versus-speed curve to determine the speed at which maximum torque occurs. This is peak torque speed. If maximum torque occurs in a flat region of the torque-versus-speed curve, your peak torque speed is the midpoint between the lowest and highest speeds at which the trace reaches the flat region. For purposes of this paragraph (c)(3), a flat region is one in which measured torque values are within 2% of the maximum recorded value. Identify your reference intermediate speed as one of the following values:

(d) *Generating reference torques from normalized duty-cycle torques.* Transform normalized torques to reference torques using your map of maximum torque versus speed.

(1) *Reference torque for variable-speed engines.* For a given speed point, multiply the corresponding % torque by the maximum torque at that speed, according to your map. If your engine is subject to a reference duty cycle that specifies negative torque values (*i.e.*, engine motoring), use negative torque for those motoring points (*i.e.*, the motoring torque). If you map negative torque as allowed under §1065.510 (c)(2) and the low-speed governor activates, resulting in positive torques, you may replace those positive motoring mapped torques with negative values between zero and the largest negative motoring torque. For both maximum and motoring torque maps, linearly interpolate mapped torque values to determine torque between mapped speeds. If the reference speed is below the minimum mapped speed (*i.e.*, 95% of idle speed or 95% of lowest required speed, whichever is higher), use the mapped torque at the minimum mapped speed as the reference torque. The result is the reference torque for each speed point.

(2) *Reference torque for constant-speed engines.* Multiply a % torque value by your maximum test torque. The result is the reference torque for each point.

(3) *Required deviations.* We require the following deviations for variable-speed engines intended primarily for propulsion of a vehicle with an automatic transmission where that engine is subject to a transient duty cycle with idle operation. These deviations are intended to produce a more representative transient duty cycle for these applications. For steady-state duty cycles or transient duty cycles with no idle operation, these requirements do not apply. Idle points for steady state duty cycles of such engines are to be run at conditions simulating neutral or park on the transmission.

(i) Zero-percent speed is the warm idle speed measured according to §1065.510(b)(6) with CITT applied, *i.e.*, measured warm idle speed in drive.

(ii) If the cycle begins with a set of contiguous idle points (zero-percent speed, and zero-percent torque), leave the reference torques set to zero for this initial contiguous idle segment. This is to represent free idle operation with the transmission in neutral or park at the start of the transient duty cycle, after the engine is started. If the initial idle segment is longer than 24 s, change the reference torques for the remaining idle points in the initial contiguous idle segment to CITT (*i.e.*, change idle points corresponding to 25 s to the end of the initial idle segment to CITT). This is to represent shifting the transmission to drive.

(iii) For all other idle points, change the reference torque to CITT. This is to represent the transmission operating in drive.

(iv) If the engine is intended primarily for automatic transmissions with a Neutral-When-Stationary feature that automatically shifts the transmission to neutral after the vehicle is stopped for a designated time and automatically shifts back to drive when the operator increases demand (*i.e.*, pushes the accelerator pedal), change the reference torque back to zero for idle points in drive after the designated time.

(v) For all points with normalized speed at or below zero percent and reference torque from zero to CITT, set the reference torque to CITT. This is to provide smoother torque references below idle speed.

(vi) For motoring points, make no changes.

(vii) For consecutive points with reference torques from zero to CITT that immediately follow idle points, change their reference torques to CITT. This is to provide smooth torque transition out of idle operation. This does not apply if the Neutral-When-Stationary feature is used and the transmission has shifted to neutral.

(viii) For consecutive points with reference torque from zero to CITT that immediately precede idle points, change their reference torques to CITT. This is to provide smooth torque transition into idle operation.

(4) *Permissible deviations for any engine.* If your engine does not operate below a certain minimum torque under normal in-use conditions, you may use a declared minimum torque as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is connected to a hydrostatic transmission and it has a minimum torque even when all the driven hydraulic actuators and motors are stationary and the engine is at idle, then you may use this declared minimum torque as a reference torque value instead of any reference torque value generated under paragraph (d)(1) or (2) of this section that is between zero and this declared minimum torque.

(e) *Generating reference power values from normalized duty cycle powers.* Transform normalized power values to reference speed and power values using your map of maximum power versus speed.

(1) First transform normalized speed values into reference speed values. For a given speed point, multiply the corresponding % power by the mapped power at maximum test speed, f_{ntest}, unless specified otherwise by the standard-setting part. The result is the reference power for each speed point, P_{ref}. Convert these reference powers to corresponding torques for operator demand and dynamometer control and for duty cycle validation per 1065.514. Use the reference speed associated with each reference power point for this conversion. As with cycles specified with % torque, linearly interpolate between these reference torque values generated from cycles with % power.

(2) Permissible deviations for any engine. If your engine does not operate below a certain power under normal in-use conditions, you may use a declared minimum power as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is directly connected to a propeller, it may have a minimum power called idle power. In this case, you may use this declared minimum power as a reference power value instead of any reference power value generated per paragraph (e)(1) of

this section that is from zero to this declared minimum power.

[73 FR 37324, June 30, 2008, as amended at 73 FR 59330, Oct. 8, 2008; 75 FR 23045, Apr. 30, 2010; 76 FR 57453, Sept. 15, 2011]

EFFECTIVE DATE NOTE: At 78 FR 36398, June 17, 2013, §1065.610 was amended by revising paragraph (c)(3), effective Aug. 16, 2013. For the convenience of the user, the revised text is set forth as follows:

§ 1065.610 Duty cycle generation.

* * * * *

(c) * * *

(3) *Intermediate speed.* If your normalized duty cycle specifies a speed as ''intermediate speed,'' use your torque-versus-speed curve to determine the speed at which maximum torque occurs. This is peak torque speed. If maximum torque occurs in a flat region of the torque-versus-speed curve, your peak torque speed is the midpoint between the lowest and highest speeds at which the trace reaches the flat region. For purposes of this paragraph (c)(3), a flat region is one in which measured torque values are within 2% of the maximum recorded value. Identify your reference intermediate speed as one of the following values:

(i) Peak torque speed if it is between (60 and 75) % of maximum test speed.

(ii) 60% of maximum test speed if peak torque speed is less than 60% of maximum test speed.

(iii) 75% of maximum test speed if peak torque speed is greater than 75% of maximum test speed.

* * * * *

§ 1065.630 1980 international gravity formula.

The acceleration of Earth's gravity, a_g, varies depending on your location. Calculate a_g at your latitude, as follows:

$$a_g = 9.7803267715 \cdot [1 + s \; 5.2790414 \cdot 10^{-3} \cdot \sin^2(\theta) + 2.32718 \cdot 10^{-5} \cdot \sin^4(\theta) + 1.262 \cdot 10^{-7} \cdot \sin^6(\theta) + 7 \cdot 10^{-10} \cdot \sin^8(\theta)] \quad \text{Eq. 1065.630-1}$$

Where:

θ = Degrees north or south latitude.

Example:

$\theta = 45°$

$a_g = 9.7803267715 \cdot (1+$
$5.2790414 \cdot 10^{-3} \cdot \sin^2(45) +$
$2.32718 \cdot 10^{-5} \cdot \sin^4(45) +$
$1.262 \cdot 10^{-7} \cdot \sin^6(45) +$
$7 \cdot 10^{-10} \cdot \sin^8(45)$
$a_g = 9.8178291229 \text{ m/s}^2$

§ 1065.640 Flow meter calibration calculations.

This section describes the calculations for calibrating various flow meters. After you calibrate a flow meter using these calculations, use the calculations described in §1065.642 to calculate flow during an emission test. Paragraph (a) of this section first describes how to convert reference flow meter outputs for use in the calibration equations, which are presented on a molar basis. The remaining paragraphs describe the calibration calculations that are specific to certain types of flow meters.

(a) *Reference meter conversions.* The calibration equations in this section use molar flow rate, $\dot{n}_{ref}$, as a reference quantity. If your reference meter outputs a flow rate in a different quantity, such as standard volume rate, $\dot{V}_{stdref}$, actual volume rate, $\dot{V}_{actref}$, or mass rate, $\dot{m}_{ref}$, convert your reference meter output to a molar flow rate using the following equations, noting that while values for volume rate, mass rate, pressure, temperature, and molar mass may change during an emission test, you should ensure that they are as constant as practical for each individual set point during a flow meter calibration: